DISTRIBUTION OF SURFACE FEATURES OF SNOW COVER IN MIZUHO PLATEAU

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Abstract: Studies have been made of surface features such as the sastrugi, the dune and the glazed surface which represent stages of deposition-erosion process of the snow surface of the ice sheet. A descriptive method is established on the surface features and surface conditions from a standpoint of these stages of genetic process. Surface features are genetically classified into three categories; depositional form, erosional form, and long-term hiatus form which is widely distributed as a glazed surface and is related closely to the absence of annual layers. The present paper describes the first attempt to discuss the characteristics of these surface features and their significance in the surface condition and snow stratigraphy.

Prevailing wind systems of Mizuho Plateau related to erosion and deposition processes are analyzed from the directional aspect of the surface features. It is found from the analysis that the one- and two-wind systems are related to the depositional and erosional processes and that a variation of wind system can almost correspond to that of surface condition.

Mizuho Plateau can be divided into four regions on the one hand on the basis of the regional characteristics of the surface condition which is related closely to the mass budget mechanism of each region.

Mizuho Plateau can be divided, on the other hand, into three regions on the basis of the regional characteristics of the mass balance. It can be estimated that their boundaries exist at 1800 m and 3000–3200 m in elevation above sea level.

1. Introduction

Many types of surface features, such as the sastrugi, the snow dunes and the pitted pattern, are distributed on the surface of the Antarctic ice sheet in various degrees of scale and occurrence as a result of interaction between the air and the ice sheet surface; the smooth and glazed surface should also be considered as a kind of surface feature, although it differs from other features which are generally distributed in a zonal form with a certain width and orientation.

Studies have been made of surface features of the ice sheet by many investigators from various viewpoints of morphology, meteorology and snow stratigraphy. Characteristics of surface features have been observed along traversed routes in Mizuho Plateau by many investigators of the Japanese Antarctic Research Expedition (JARE) oversnow traverses since IGY (YOSHIDA *et al.*, 1962; FUJIWARA and ENDO, 1971; AGETA, 1971; WATANABE and AGETA, 1972).

Individual arrangement and scale of a feature at a given place is regarded as an environmental indicator. Such a feature may indicate a climatic conditions related to its formation. A surface condition which is characterized by an individual feature with a specific arrangement and occurrence takes place as a whole in a limited area, much varying from nearby surface conditions. In this sense, the typical surface conditions are distributed in zonal forms of sastrugi, dune and a glazed surface.

According to stratigraphical studies and observations of actual changes of the surface, it is found that a surface condition which remained stable for years can change to a different one in any year on the one hand.

On the other hand, a variation of surface condition occurs during a one-year period, depending on the seasonal change of climatic condition. This cyclic change of the surface feature constitutes the process of surface layer formation. After falling snow particles have settled on the surface, they change to a firn layer passing through the stages represented by various type of surface features. From the stratigraphical viewpoint, the knowledge of a surface condition and its change provides a basic piece of information on sedimentation of a surface snow layer. This study of regional characteristics of surface features and conditions in Mizuho Plateau have been made on the basis of the data obtained by the oversnow traverses conducted in two summer seasons of 1970–1971 and 1974–1975.

2. Descriptive Method of Surface Features and Surface Conditions

The morphological classification of surface features has been discussed by several investigators (KOTLYAKOV, 1966; DOUMANI, 1967; FUJIWARA, 1971). Terms used in the classification are common with each other. For the studies on the genetic process of surface features and their interrelations, the following factors are essential for the description: a) appearance indicating a stage of genetic process; b) scale correlated to a quantitative condition such as the kinetic energy of winds and the intensity of deposition; c) occurrence showing a genetic interrelation among the features and related to the relative comparison of the surface conditions. An observed surface is always in deposition-erosion process as will be described later, and so the external forms of an individual feature as well as of its group would change successively in accordance with a change in the meteorological condition. The descriptive method used in the field observation at Mizuho Plateau is shown in Table 1. Surface features are generalized and classified genetically into three major categories: a) depositional form, b) erosional form and c) long-term hiatus form. Successive changes of form and occurrence

Table 1. Morphologic classification of surface features.

	Form	Scale	Occurrence	
Depositional form	Barchan		single doubles and compound	
	Dune		isolated leaned	
Erosional form	Sastrugi	L: 70< M: 30–70 S: <30	isolated grouped banded	sporadic occurrence crowded occurrence
	Erosion pit			
	Smooth surface			
Long-term hiatus form	Glazed surface		without thermal crack with thermal crack	

are indicated by arrow lines in the table, in which a smooth surface represents a state of the surface condition where sastrugi and dunes are less developed ready to change into a state of the glazed surface covered with the multilayered ice crust described later. The long-term hiatus form, which is mostly a surface in appearance, has been excluded in the classification hitherto made despite its extensive distribution and close relation to katabatic characteristics. The distribution of the glazed surface in other terrains of the continent was reported (LISTER, 1959; GIOVINETTO, 1963). Usually the cracks, patterned in the form of polygons, are most visible on the glazed surface. A crack formation, having a depth of 2–3 meters, is presumed to have been caused by thermal expansion and contraction of the hard surface, and so the term thermal crack has been adopted (WATANABE, 1972).

A certain relation between the surface condition and the deposition-erosion process was found from the results of surface observations, stratigraphical studies

Table 2. Successive changes of surface condition in the predominant katabatic winds region.

Deposition-erosion process	Surface condition	Relative assessment
Active stage	Sastrugi zone Dune zone	L-class sastrugi zone—(R)
		Rough surface
Inactive stage	Smooth surface zone	
		Smooth surface
Equilibrium stage (or Stable)	Glazed surface zone (Long-term hiatus zone)	Glazed surface zone—(S)

←Migration of surface condition (Moving surface) and stake measurements of accumulation. Successive changes of surface condition are shown in Table 2. The surface condition of an area can be expressed by the following items of observations:

i) Description of type, scale and occurrence of a surface feature at a given place was made. Important information on the condition of the surface was provided by measuring the directional qualities of the feature if possible.

ii) When a specified type of surface feature such as sastrugi, dune or glazed surface was well developed and concentrated in a limited area, the area was accordingly called a sastrugi zone, a dune zone or a glazed surface zone. Location, width of a zone and elevation of a border were recorded. On the basis of the average scale and the relative density of surface feature developed at a given place, a zone was graded into three classes, L, M, and S in decreasing order except for the glazed surface. iii) Relative assessment of a surface condition was made by grading of roughness. As a standard of roughness of a surface, the relief occurrence of a L-class sastrugi zone was taken as the maximum roughness (R), and that of glazed surface as the minimum roughness (S). Roughnesses of a surface were estimated between the maximum and the minimum.

3. Surface Conditions of Mizuho Plateau

Surface conditions of Mizuho Plateau were recorded along the traverses routes in 1969–1970 and 1975–1976 by applying the descriptive method described in the previous section.

Based on all the relevant data obtained by the observations, Fig. 1 gives a sketch of individual features distributed in the zonal form along the traverse routes, their directions being shown relative to the direction of each route. In this figure, surface features and zones characterized by them are shown according to their elevations. The results of roughness assessment along Routes I and J are also shown each in the right-hand column of the surface condition.

As seen in this figure, the area of Mizuho Plateau can be divided into the following three regions, one of which is further divided into two subregions:

3.1. A region from the coast line to the dry snow line, the elevation of which is in a range of 700–1000 m above sea level, annually varying with the annual variation of climatic condition

This region can be further divided into two subregions with the firn line as a boundary. The elevation of the firn line varies annually in a range of 400–500 m above sea level. The subregion lower than the firn line, where the surface slope is relatively steep, is almost covered with supperimposed ice and/or exposed ice during the summer season. The subregion higher than the firn line is characterized by occurrence of melting at the surface during summer, but in other seasons

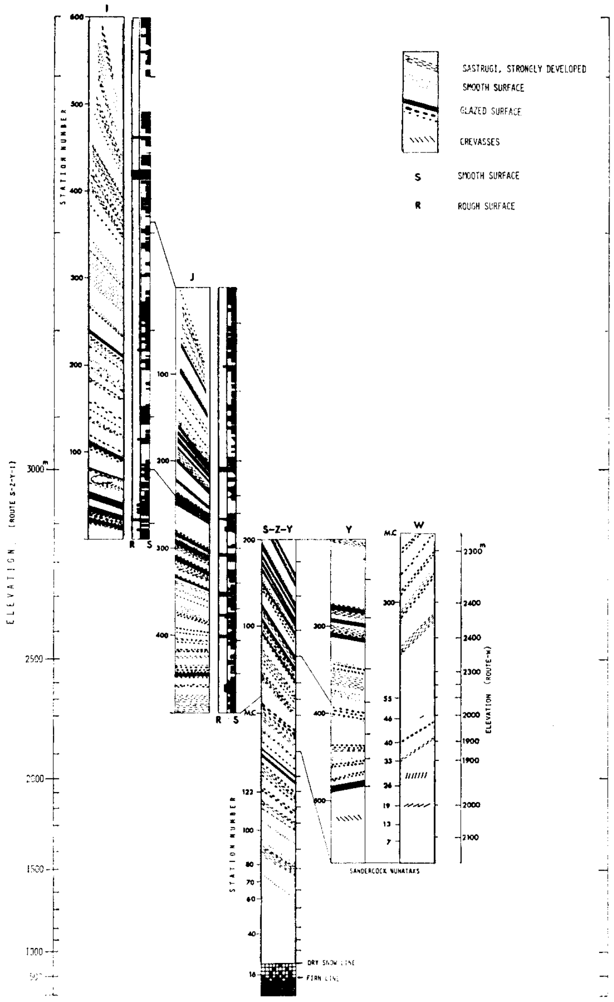


Fig. 1. Distribution of the surface conditions along the traverse routes Mizuho Plateau.

the surface condition of this subregion is the same as that of the region higher than the dry snow line.

3.2. *A region between the dry snow line and the lower limit of development of a glazed surface (1000–1800 m a.s.l.)*

As is seen in Fig. 1, the lowest elevation where a glazed surface develops is 1800 m along Route S. In the region between the dry snow line and this lowest elevation, annual accumulation is comparatively large under the influence of a maritime climate, and a hiatus seldom occurs in an annual layer throughout this region (YAMADA *et al.,* 1978). In areas lower than 1500 m in this region the surface is highly rough during the colder season and then changes to a relatively smooth and even one in summer. In areas above 1500 m in this region, the surface features such as sastrugi and dunes formed in the colder season remain during the summer season. Route H in this region not included in Fig. 1 shows characteristics of surface conditions different from those along Route S. Namely along Route H, the surface is more moderate in roughness, and has accumulation 20–30% less than the surface along Route S.

3.3. A region between elevations of 1800 m and 3200 m

This region is characterized by a wide distribution of the glazed surface. It can be considered that the glazed surface occurs in a belt-shaped zone with an interval of 10–20 km along the direction of the prevailing wind. The average width in the direction normal to the prevailing wind seems to be a few kilometers, but some of the most developed belts are some ten kilometers in width. Frequency of their occurrence increases in the range of elevation from 2500 m to 3100 m.

The smooth surface and the patch-like glazed surface were seen in the vicinity of the glazed surface. These surface features can be presumed to represent a transitional form, namely, from a glazed surface to another rougher surface, or in reverse order.

Surface features in this region are of a relatively small scale. The surface condition is characterized by alternating occurrence of a wide smooth surface and a narrow sastrugi zone with a distinct boundary. Characteristics of a sastrugi zone in this region are different from those in other regions where the alternation of a highly developed sastrugi and a smooth surface occurs with a relatively narrow width. The elevation of 3500 m is the highest one in the observed area in Mizuho Plateau. Relative assessments of the surface condition were made along Routes I and J by drawing on the criterion of the maximum roughness in the L-sastrugi zone (R) and the minimum roughness in the glazed zone (S). The successive change model shown in Table 2 is applicable to the region higher than 1800 m. Since the coastal region has a larger snow accumulation and does not develop a glazed surface, deposition-erosion process is nearly in an equilibrium or stable stage as a result of a seasonal variation of climatic condition which brings about the smooth and even surface in summer. Both the surface conditions, namely the summer surface in the coastal region and the glazed surface in the interior region, result from the equilibrium or stable stage of the process. From another standpoint, these phenomena represent the action of surface leveling due to a climatic control in the coastal region and a topographical control in the other region.

4. Forming Processes of Surface Features

The surface features arising from the action of winds can be divided into a) free deposition, b) forced deposition and c) erosion (KOTLYAKOV, 1966). In the observed area the free deposition occurs rarely, but forced deposition takes place generally under the action of strong winds on the surface. Obstacles on the

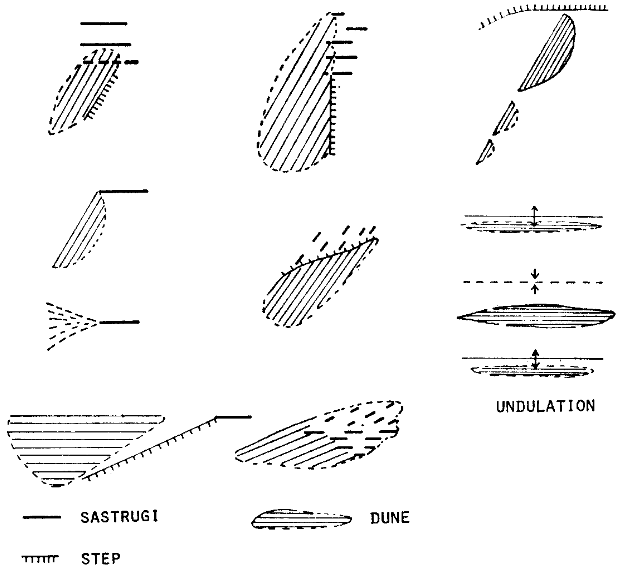


Fig. 2. Sketches of arrangements of sastrugi and dunes.

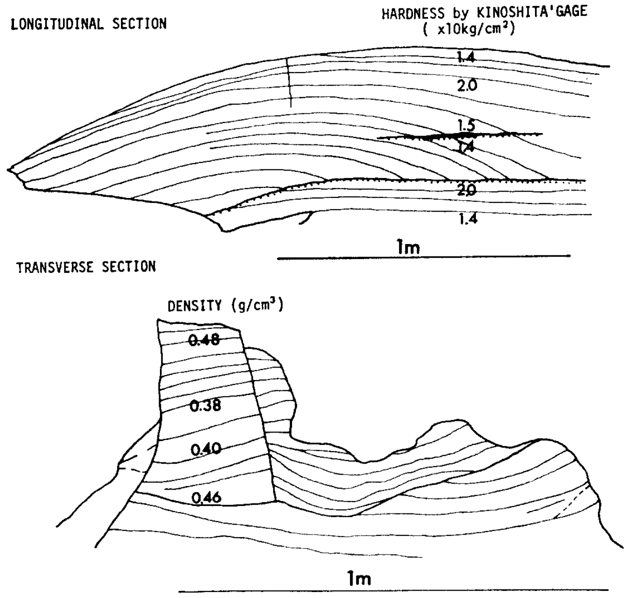


Fig. 3. Inner structure of sastrugi.

surface are necessary for deposition, of drifting snow under forced deposition, since surface obstacles would reduce the wind velocity. In this sense, sastrugi formed and distributed uniformly in the same preferred direction act as obstacles and help the formation of dunes.

During an anticyclonic weather, blowing snow is usually confined to the lower layer of the atmosphere, mostly within 2 or 3 meters above the surface. Snow particles are settled behind obstacles on the snow surface taking various forms such as barchans, tails and dunes. These deposited snow particles are removed mostly and do not remain in their initial positions and forms. After repeating a cycle of deposition and erosion during the period of a cyclonic weather, they are deposited in the form of a dune which is a relatively stable form of deposition. Subsequently dunes are partially destroyed and pitted by a wind of another direction and change to sastrugi. Sastrugi are the typical erosional form, caused by a katabatic wind carving pre-existing dunes. They generally occur in elongated forms parallel to the prevailing wind having a stratified body. Some cases of arrangements characterized by their surface features observed on the routes traversed are shown in Fig. 2. From these arrangements of sastrugi and dunes, a close relation between their frequencies of occurrence can be understood. Stratigraphical investigations were made on some of sastrugi to examine their genetic process. As one of the results, the inner structure of a sastrugi is shown in Fig. 3. As seen in the figure, this sastrugi is composed of two separable units formed under two different weather conditions. The wind stratification (lamina structure) of each unit crosses each other, showing a stratigraphical discontinuity. Sastrugi have a complicated structure in comparison with its appearance.

A consideration of discontinuity in the structure and the changing process of the surface discloses that the surface feature represents a stage in the process of deposition and erosion (deposition-erosion process). After this process, residue from both actions of deposition and erosion constitute a surface layer of the ice sheet as a positive mass balance at the place of occurrence.

If viewed from another standpoint, a serial process of topographic change of the surface feature, from dunes to sastrugi can be regarded as a redistribution process of deposited snow. The stage of deposition-erosion process is not the same throughout the year and also differs from region to region. In the coastal region and some parts of the higher region, the equilibrium or stable stage of the process may occur in summer and the active stage in winter. In the interior region, the process may be more complicated. As a remarkable phenomenon of the equilibrium or stable stage of deposition-erosion process, surface leveling is important. In summer, as a result of decrease in cyclonic activities and accumulation rate both intensive deposition and erosion are interrupted and then the surface would be leveled by the sweeping effect of winds. Such a process is called "under a climatic control" in this paper. In the region where the accumulation rate shows a seasonal variation, surface leveling occurs widely in summer, and so such a flat surface is called a summer surface. Another type of surface leveling occurs in the higher region, where a glazed surface is formed by change of a wind flow due to the topographic condition. Such a process is called "under a topographic control" in this paper.

5. Prevailing wind Systems Related to Formation of Surface Features

5.1. Wind systems related to erosion

A sastrugi and pitted pattern represent forms eroded by katabatic winds. The long axis of a sastrugi and an elongated pit is oriented along the direction of the wind which is the cause of their formation. In some regions of Mizuho Plateau, the occurrence of two or more distinct directions of sastrugi were found at a site. The variation of the direction of a surface feature with time is one of interesting problems. Some investigators observed a seasonal variation of sastrugi direction in the vicinity of Mizuho Camp and on the traverse routes (AGETA, 1971; WATANABE, 1972; OKUHIRA and NARITA, 1978). According to their reports, clear evidence of the variation was not found yet, but AGETA (1971) has pointed out its possibility and suggested that a more detailed study on the feature is needed.

Sastrugi are formed by the action of katabatic winds, but the surface is simul-

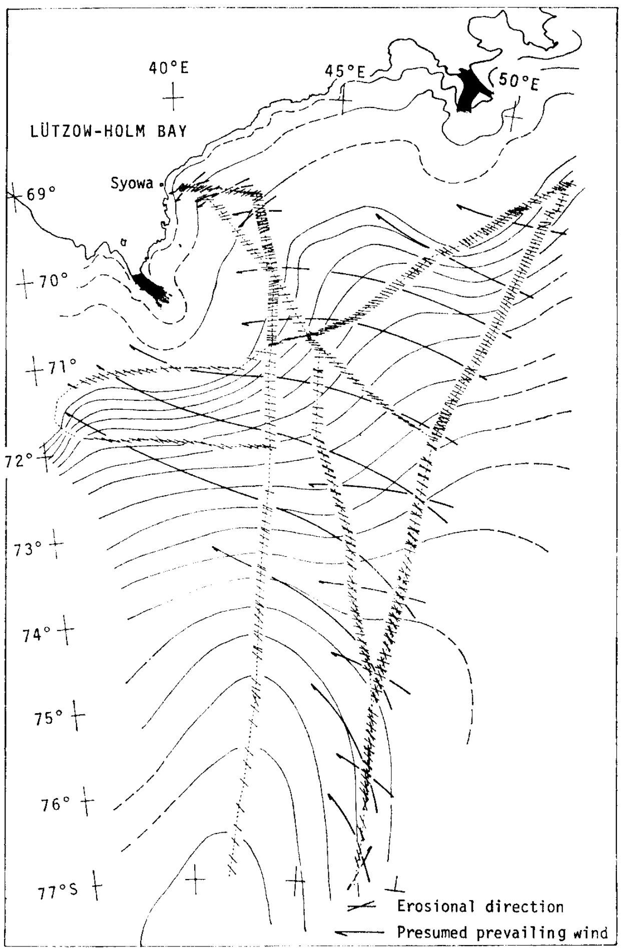


Fig. 4. Directions of erosional feature on the surface and presumed prevailing wind in Mizuho Plateau.

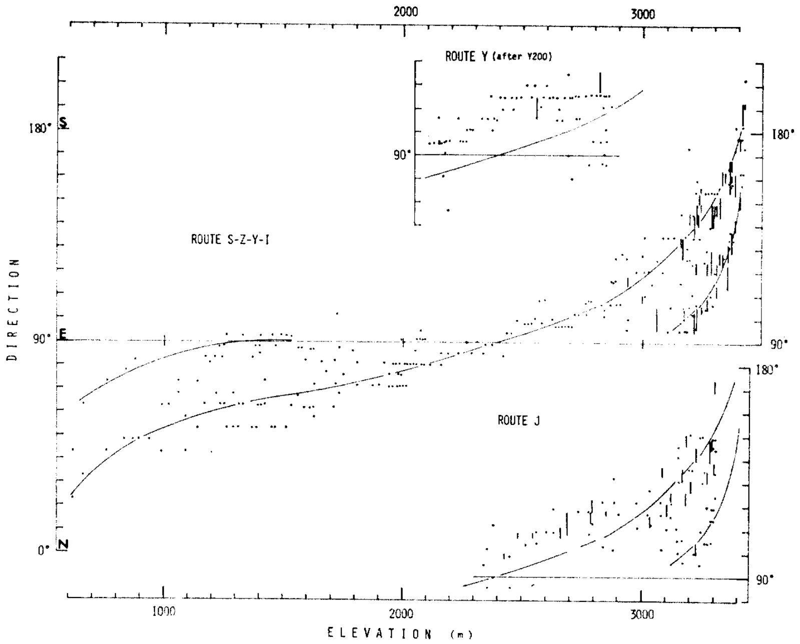


Fig. 5. Relation between erosional direction and elevation along the traverse routes.

taneously affected by a cyclonic storm with a different wind direction. Since the later lasts only for a very short period, sastrugi are not modified by it. From the observation in Mizuho Plateau, it can be concluded that the distribution of direction of sastrugi in the area indicates a system of katabatic winds in Mizuho Plateau.

Information of the directions of surface features in Mizuho Plateau has been reported by several investigators (YOSHIDA *et al.*, 1962; FUJIWARA, 1964, 1971; AGETA, 1971; WATANABE and AGETA, 1972; WATANABE, 1978).

A compiled map of directions of sastrugi obtained by field observations of 1970–1971 and 1973–1975 is shown in Fig. 4 on the basis of numerical data reported in JARE Data Reports, No. 17 and No. 36, respectively. The information obtained from the Syowa-South Pole traverse (FUJIWARA and ENDO, 1971) is also shown in this figure where solid lines indicate a presumed system of katabatic winds. A two-wind system is found in both the coastal and the interior region. The regional characteristics of katabatic wind system can be examined by the relation between direction and elevation along the routes, as shown in Fig. 5. A veriation of direction can be seen in the relation between the two along Route S-Z-Y-I, as indicated by a continuous line.

The direction of sastrugi is 190° in the azimuth at 3400 m and then changes gradually to northward reaching 20° in the azimuth at 700 m. In the regions lower than 1500 m and higher than 3000 m, a two-wind system is found. One direction in the two-wind system deviates southward from the other in the lower region, and deviates north-ward in the higher region, the deviation angle being 20°–30° in both cases. The tendency of the directional variation along Route J is almost the same as that of Route S-Z-Y-I, but some difference is found in that of a part of Route Y (after Y200). In the region where the route toward Sandercock Nunataks runs away from station Y200, the surface is funnelled down to the Rayner Glacier. Therefore, this region is topographically different from the region crossed by the other Route S-Z-Y-I-J the surface wind in this region is affected by such a surface morphology.

5.2. Wind systems related to deposition

Depositional forms of surface features include the dune and the barchan-like form of deposition. The dune-form deposition occurs on the lee side of obstacles on the snow surface. Directions of depositional forms are more complicated than

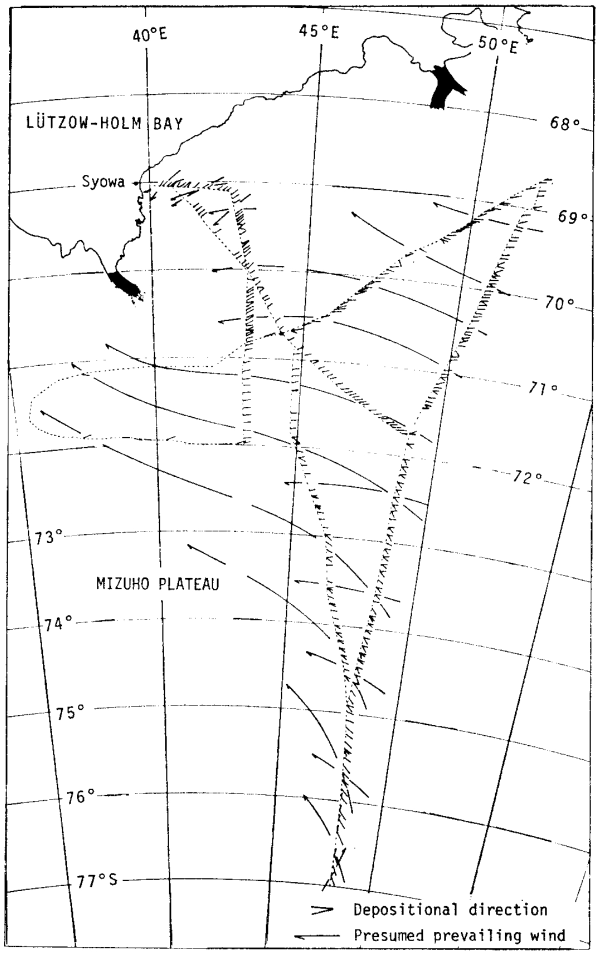


Fig. 6. Directions of depositional feature on the surface in relation to the prevailing wind in Mizuho Plateau.

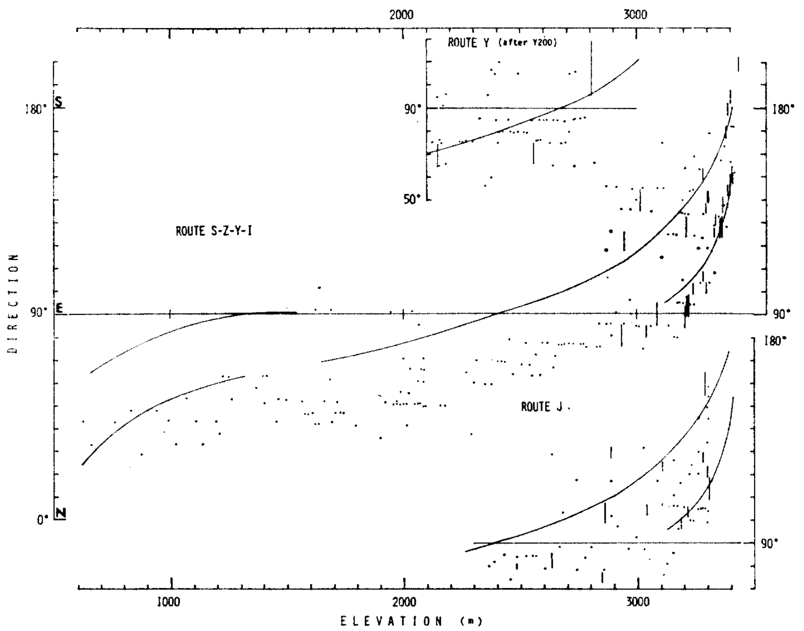


Fig. 7. Relation between depositional direction and elevation along the traverse routes.
The solid line in this figure is the same as that in Fig. 5.

those of erosional forms, so that confusion and misunderstanding affect the estimation of their direction. Judging from the existence of discontinuity in stratification of sastrugi as described before and also from the result of direct observations of surface phenomena at Mizuho Camp (OKUHIRA and NARITA, 1978), the winds related to deposition are not in fixed directions at a given place during the period of a cyclonic weather condition. But the most frequent wind direction corresponds to the regional characteristics of deposition. Fig. 6 gives a compiled map of preferred direction of deposition obtained from field observation of 1970–1971 and 1973–1975, as reported in JARE Data Reports, No. 17 and No. 36 respectively, which provided the numerical data of the direction in this figure. Since the preferred directions of deposition are closely related to those of erosion, the katabatic wind system is shown as an index of erosion in this figure. A two-wind system is seen only in the region higher than 2800 m. The relation between direction and elevation is shown in Fig. 7, in which a regional variation of erosional directions is shown in solid lines in comparison with the both tendencies. In the region between 1700 m and 3200 m in elevation, a difference of directions is constantly about 30°, deviating northward.

The similar tendency of directional changes of depositions was observed also in the region higher than 3200 m, where the difference decreased and another wind direction corresponding to that of erosion occurred also. In the coastal region there is no evident correlation between the directions of erosion and deposition. A continuous variation of direction of the depositional wind in the region lower than 1500 m shows a tendency to change gradually closer to be parallel to the coastal contour lines, deviating southward by 30°–40° from the direction of the erosional wind system.

5.3. Regional characteristics of wind systems

Regional characteristics of wind systems are summarized in Table 3 in relation to geomorphological elements. According to their characteristics, Mizuho Plateau is divided broadly into three regions. Two-winds systems of the erosional nature are seen in both the coastal and the interior region. In the latter region, a depositional 2-wind system also exists. In contrast with these regions, intermediate region II between 1800 m and 3000 m in elevation is characterized by a one-wind system of the erosional and the depositional nature. The wind system related to deposition is strongly influenced by a cyclone, but the erosional wind system is constituted by the constant flow of katabatic winds outward to the periphery of the ice sheet.

BALL (1960) studied the mechanism of katabatic winds theoretically. According to his study, katabatic winds occur when the inversion strength is 10°C and the slope is 2×10^{-3}. KOBAYASHI and YOKOYAMA (1976) reported from the observation results that in Mizuho Plateau the inversion strength is 5°C in summer and 15–20°C in winter. Depending on these results, the upper limit of katabatic generation can be estimated at 3000 m above sea level where the slope is 2×10^{-3}.

Table 3. Relation between prevailing wind systems and geomorphological features.

Region	Elevation Lower	Elevation Upper	Slope	Wind system	Angle between* Range	Angle between* average	Characteristics of wind
I	Firn line		0.014	Erosional 2-wind systems	30–60°(N) 40–90°(N)	45° —	Pure katabatic
	—	1800 m	— 0.007	Depositional 1-wind system	30°(N) 20°(S)		Cyclonic
II	1800 m		0.007	Erosional 1-wind system	25–35°(N)	30°	Pure katabatic
	—	3000 m	— 0.002	Depositional 1-wind system	15–40°(N)	30°	Cyclonic
III	3000 m			Erosional 2-wind systems	30–90°(N) 20–60°(N)	— —	Coincidence between erosional and depositional wind systems
	—		0.002	Depositional 2-wind systems	— —		

* Erosional wind system: wind direction and slope direction

* Depositional wind system: erosional and depositional wind direction

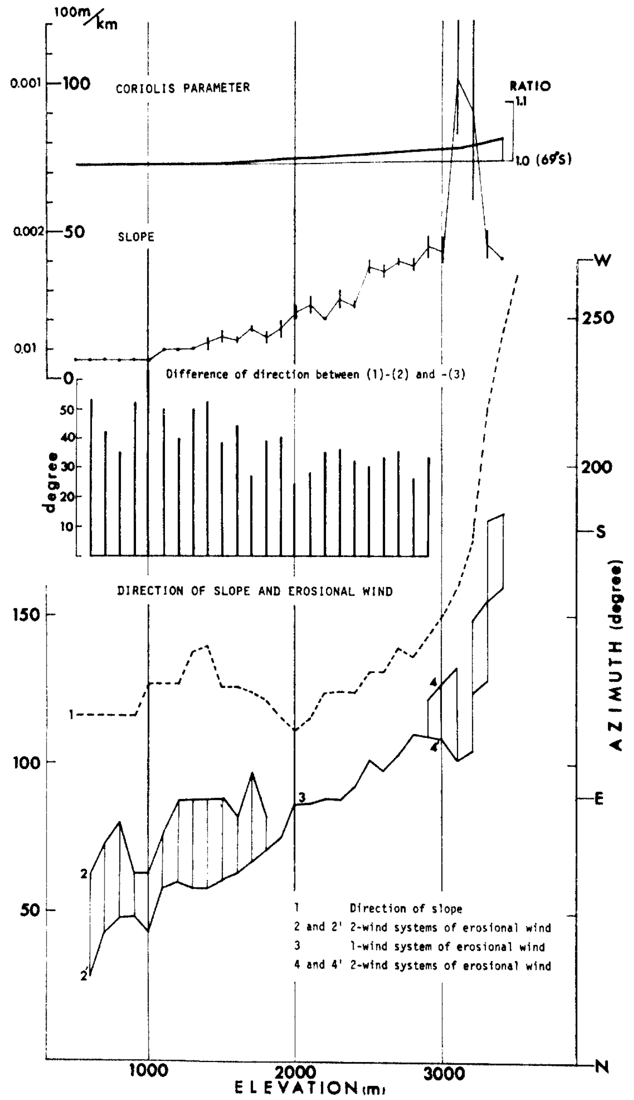


Fig. 8. Relation between direction of katabatic wind and geomorphological elements in Mizuho Plateau.

This elevation corresponds to the lower boundary of region III in Table 3. In BALL's theory (1960), the angle β between the direction of katabatic winds and the line of the greatest slope is given by:

$$\text{Sin}\,\beta = \frac{Vn \cdot f}{g^* \cdot \alpha}$$

where

Vn: normal speed of katabatic winds when their flow is uniform
f: Coriolis parameter
g^*: modified gravitational acceleration given by $g^* = \theta' g/\theta$, where θ is the

temperature and θ' the inversion strength

α: surface slope

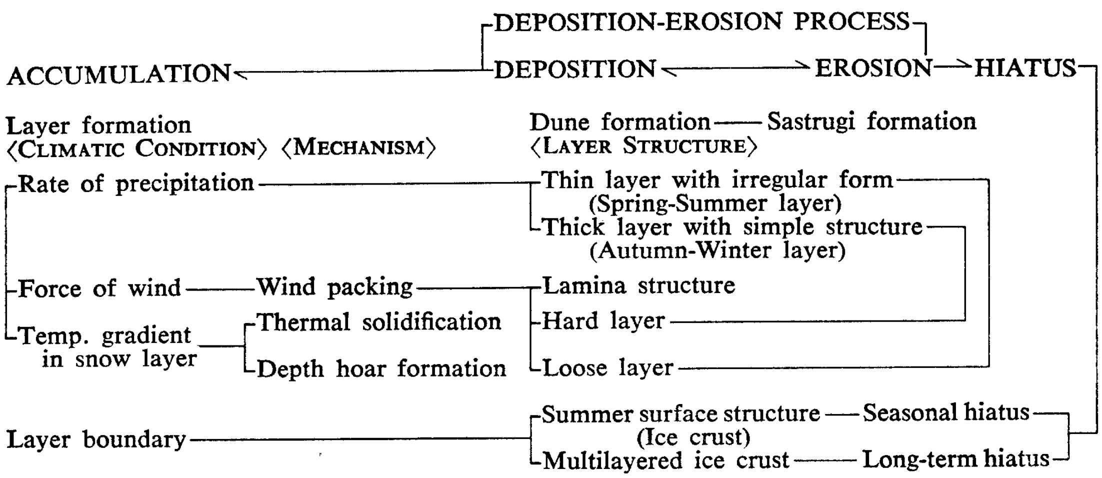
The angle β can be determined by the ratio of the geostrophic accelation $Vn \cdot f$ to the katabatic accelation $g^* \cdot \alpha$. Relations between the direction of the katabatic winds observed in Mizuho Plateau and the geomorphological elements are shown in Fig. 8 which gives the average azimuth of katabatic winds and the line of the greatest slope at every interval of 100 m in elevation along Route S-Z-Y-I. The Coriolis parameter f is shown as a relative ratio to the value of 69°S, which increases by 4% at 75–76°S. The surface slope (ratio of a unit distance to a difference of the elevations) is more than 0.01 in the coastal region between 500 m and 1000 m in elevation, and 0.001–0.002 in the interior region between 3000 m and 3400 m. The angle β shows regional characteristics of katabatic winds. In region II where the elevation ranged between 1800 m and 3000 m, the angle β averages 30° with a relatively small deviation. This characteristic katabatic wind may be the so-called "pure katabatic" defined by BALL (1960). In the coastal region, the one wind of the two-wind system, which is stronger in the southerly component of the two, may also be identified as "pure katabatic", whereby the same tendency of the angle can been seen for this wind as well. Observed heights of inversion at Mizuho Camp are reported by KOBAYASHI and YOKOYAMA (1976) as 600 m in winter and 250 m in summer.

It is reasonable, therefore, to assume that the inversion strength is 10°C and the height of inversion 200–400 m. If so, BALL's nomogram gives the value of β as 20°–40°, which is in agreement with the observed one.

6. Relations between Surface Conditions and Snow Stratigraphy

The occurrence and scale of a feature on the surface at given time and place

Table 4. Relation between surface condition and snow stratigraphy.



indicate a transient stage of deposition-erosion process then and there. Therefore, the pre-existent feature is not reflected perfectly in the stratigraphy of a snow layer beneath the surface observed. A part or the entire portion of the feature is eroded probably, and deposition of a small scale may occur at the same time in the other portion. When deposition continues on a large scale after a shorter hiatus of deposition, and/or deposition-erosion process is in an equilibrium or stable stage, the surface feature at a specific time will be reflected in the surface snow layer of the ice sheet. A snow layer formed by such a process can be defined as a "unit layer". It is a net balance after a process of deposition-erosion; it indicates environmental conditions during their formation. In this case the environmental conditions means climatic condition such as rate of precipitation, atmospheric temperature, wind, and also stage of the process of deposition and erosion. Depending on the environmental conditions, various types of unit layers are formed, for example, wind stratification layer formed by wind-packing. A combination of types of unit layers is important in snow stratigraphy. On the wall of a pit, unit layers can be identified by the boundaries between two layers. Such a layer boundary is considered to have been formed during a hiatus in deposition-erosion process. When a boundary is composed of a multilayered ice crust, it indicates the occurrence of a long-term hiatus. An example of multilayered ice crust is a 6-layered ice crust which was observed in a glazed surface at Mizuho Camp (WATANABE, 1972). The hiatus phenomenon can be classified into two types, depending on the time scale: seasonal and long-term. The typical texture of the seasonal hiatus is the summer surface structure with a relatively flat horizontal plane and a well-developed ice crust. This boundary of surface layers is especially developed in the coastal region and is used effectively as a stratigraphic criterion for determination of an annual layer. The long-term hiatus in the formation of annual layers, namely, the absence of annual layers, is often observed in the surface snow of the katabatic region where the elevation is between 1800 m and 3200 m. The absence of annual layers is not found in the region between the firn line and 1700 m in elevation from both the results of stake measurements and stratigraphical analyses.

The relations between surface conditions and snow stratigraphy are summerized in Table 4.

Characteristics of surface layers investigated in Mizuho Plateau will be discussed in another paper.

7. Concluding Remarks

Summarizing the results described in this paper, a surface feature can be considered to represent a stage of changing process of snow from deposition to formation of surface snow layer. This process depends on the regional climate and topographical condition which are related to each other through the air and surface interaction. The surface condition indicates the regional characteristics of such a process.

Regional variations of surface condition, wind system and process of surface layer formation are summarized in Table 5 as a system of mass budget of the ice sheet.

Each of items in the Table has been discussed in detail previously. From a viewpoint of mass balance, Mizuho Plateau can be divided into three characteristic regions. The region of elevation between 1800 m and 3000–3200 m is characterized by the glazed surface distribution and is affected strongly by winds, the

Table 5. Regional characteristics of surface conditions.

Elevation (m)	Surface conditions	Hiatus	Wind system	Deposition-erosion process	
3500			(Erosional) 2-wind systems (Depositional) 2-wind systems	Uniform layer formation	
	Upper limit of glazed surface		REGION III		
3000	Glazed surface distribution well developed	Long-term hiatus in annual layer formation	(Erosional) 1-wind system (Depositional) 1-wind system	Sporadic annual layer formation	Topographic control
2500	GLAZED SURFACE DISTRIBUTED		REGION II		
2000	Lower limit of glazed surface				
1500	Lower limit of sastrugi zone in summer	Summer hiatus in seasonal layer formation	(Erosional) 2-wind systems (Depositional) 1-wind system	Continuous annual layer formation	Climatic control
1000	Dry snow line		REGION I		
500	Firn line	Ablation Zone		bare ice surface in summer	
0					

so-called "pure katabatic".

Since the characteristics of this region are the discontinuous occurrence of annual layers and the hiatus, the places of positive mass balance are found as patches in this region.

Since the coastal region, lower than 1700–1800 m of elevation, is under the influence of the maritime climate, the positive mass balance occurs all over, and accordingly this region is covered by a sheet-like annual layer.

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